ANALYSIS OF THE QBSS LOAD ELEMENT OF IEEE 802.11E FOR A PRIORI ESTIMATION OF SERVICE QUALITY

BURAK SIMSEK *
Institut für Informatik, HU Berlin
Unter den Linden 6
10009 Berlin

KATINKA WOLTER †
Institut für Informatik, HU Berlin
Unter den Linden 6
10009 Berlin

HAKAN COSKUN ‡
ETS, TU Berlin
Franklinstr.28/29
10587 Berlin

Abstract: IEEE is preparing its new WLAN standard 802.11e in order to be able to cope with the emergent needs of real time traffic over wireless networks. Within this new standard there is an element called the QBSS (QoS enhanced basic service set) load element which should help in solving the problem of candidate access point selection.In this paper we show that QBSS load element can in many cases make incorrect decisions because of the complex interactions between the newly introduced functions EDCA (enhanced distributed channel access) and HCCA (hybrid coordination function controlled channel access). We examine some cases with unexpected correlation between the QBSS load element parameters and the defined QoS (quality of service) metrics. Additionally, we show that the correlation between the number of traffic streams using the same priority and the defined QoS metrics is substantially higher. Therefore we suggest an adjustment in the QBSS load element which enlarges its capabilities in the candidate access point selection.

1 Introduction

The tremendous success of the 802.11 technology is highly visible. The WLAN standard 802.11 has already proven to be one of the best marketing products for wireless services. Through Quality of Service (QoS) enhancements which are still developing, QoS demanding services such as Video on demand, Voice over IP (VoIP) and gaming will also find its place in a wireless setting. A crucial feature which is required to enable flawless operation of the mentioned services is guaranteed traffic treatment, in the sense that the needed traffic characteristics are adhered by the wireless network infrastructure. The IEEE 802.11e task group envisages solving this problem in the near future with a new standard [1] [7]. The new standard IEEE 802.11e extends the existing 802.11 standard by adding new functions targeting both differentiated and integrated services. QoS enhanced access points (QAP) cope with real-time traffic that is delay-sensitive, jitter-sensitive, error-prone etc. such as voice and video streams (see [3] for a detailed overview).

IEEE 802.11e introduces a new element called the QBSS (QoS enhanced basic service set) load element, which is part of the beacon frames generated by QoS enhanced access points (QAP) and contains information on the current traffic situation. It includes three parameters: station count, channel utilization and available admission capacity. The station count is the total number of stations currently associated with the access point. The channel utilization gives the percentage of the time the channel is sensed to be busy using either the physical or virtual carrier sense mechanism of the access point. The available admission capacity gives the amount of time that can be used by explicit admission control. These three pa-

* simsek@informatik.hu-berlin.de
† wolter@informatik.hu-berlin.de
‡ coskun@cs.tu-berlin.de
[1] current draft version is 12.0

rameters can be used on one hand by a QoS enhanced access point to decide whether to accept an admission control request and on the other hand by a wireless station to decide which of the available access points to choose.

Research in the area of QoS in 802.11 networks concentrates mainly on the evaluation of the performance of the 802.11e drafts and related improvement proposals [1, 2, 4]. In this paper we assume that QoS handling is given and works as expected, the main question we strive to answer is: Does the extension proposed in the standard 802.11e include sufficient information to evaluate the provided service quality?

We evaluate the significance of the three parameters of the QBSS load element in a simulation study using the ns-2 network[2] simulator [12], where we determine the coefficient of correlation with some QoS metric. Different QoS metrics are used depending on the type of traffic (voice, video, etc.) under consideration.

The results of our study show that none of the three QoS parameters of the QBSS load element has a significant correlation with any of the QoS metrics for the different types of traffic. We conclude that the parameters of the QBSS load element are neither sufficient nor comprehensive for describing the expected QoS. Similar results are described in [13]. Instead we found the number of already present connections of the regarded type (if we look at video traffic that is the number of already connected video transmissions) correlates strongly with the respective QoS metric as shown in [14] as well. Therefore we propose to enhance the QBSS load element by another field holding a vector of the number of existing connections with the different types of traffic.

The rest of the paper is structured as follows: After a summary of the current status of the 802.11e MAC protocol and its functionality in Section 2, we present different scenarios that were simulated with the ns-2 network simulator in Section 3. Section 4 discusses the simulation results in detail. Based on the gained results, in Section 5 we suggest an enhancement in the QBSS load element that indicates the level of provided service quality and ultimately helps in finding the best-suited QAP depending on the required QoS. Finally, Section 6 concludes this paper.

2 The Basics of the IEEE 802.11e Standard

The main idea behind the development of the IEEE 802.11e QoS facility is the lack of sufficient QoS management over WLAN. To solve this problem, the IEEE 802.11e task group introduced an obligatory function for the MAC layer called hybrid coordination function (HCF) composed of a combination of two sub functions, EDCA (enhanced distributed channel access) for prioritized channel access (similar to DiffServ) and HCCA (hybrid coordination function controlled channel access) for parameterized channel access (similar to IntServ).

In the draft, there exists a new central control mechanism of the hybrid coordination function which is called the hybrid coordinator (HC). The hybrid coordinator is responsible for the management of the use of EDCA and HCCA in a cooperative manner. Basically the hybrid coordinator makes the decision about when and how to use HCCA. The remaining time in which HCCA is not used is reserved for EDCA. A possible combination of EDCA and HCCA usage is illustrated within the standard draft as given in Figure 1 where a CAP is the controlled access phase of the hybrid coordinator. The main idea behind both functions is that if e.g. a voice stream needs a special treatment because of its vulnerability to delay or loss of its packets, the hybrid coordination function reserves a time interval for this stream using HCCA. Within the reserved time interval which is called transmission opportunity (TXOP) no other station is allowed to send. Consequently, the voice stream can send its packets without being disturbed by other stations' transmissions. On the contrary, all stations can send their packets during EDCA. Nevertheless, high priority traffic has still more chance to access the channel than the lower priority traffic. A summary of both functions EDCA and HCCA and how the hybrid coordination function uses them is given in the following two subsections.

2.1 Enhanced Distributed Channel Access (EDCA)

The enhanced distributed channel access function is defined to offer prioritized channel access. There are up to 8 user priorities. These are assigned to each packet at higher levels depending on the type of the application (e.g. voice traffic is assigned the highest priority). The main target of the EDCA is to decrease the adverse effects of the existence of the lower priority traffic on the quality of service on the high priority traffic. At the MAC layer, user priorities are grouped into 4 access categories, each having their own queues. The access to the channel during the use of EDCA is also called a contention period (CP) because all access categories contend to win EDCA

[2] Several implementations of 802.11e mechanisms are already available

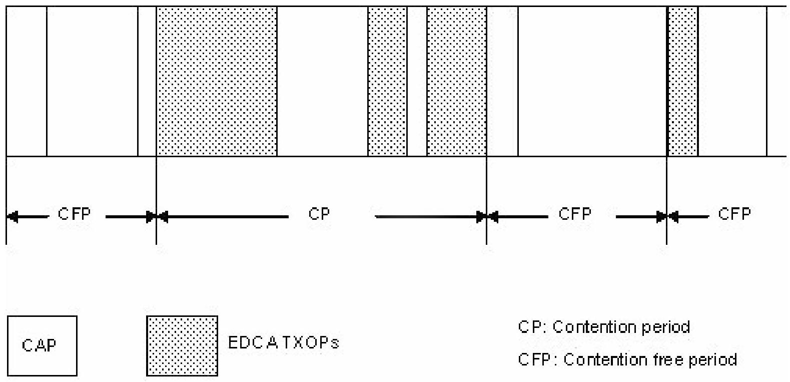


Figure 1. CAP/CFP/CP periods

TXOPs (time intervals in which a station is allowed to send its packets using EDCA). Each access category has a backoff timer that is used for the contention process. Initially the backoff times are chosen randomly from intervals called the contention windows (CW). The minimum and the maximum possible values of the contention window are are different for each access category. After a station senses the medium to be idle for a definite period of time (called arbitration interframe space (AIFS)) which is also different for each access category, uniformly distributed backoff timers are sampled. The access category which wins the EDCA TXOP sends its packets during the time interval defined in this TXOP. Additionally the length of TXOPs is defined differently for each access category. Using this protection mechanisms EDCA makes sure that high priority traffic waits less for a transmission opportunity than low priority traffic. Additionally the transmission opportunity given to high priority traffic is longer than the one given to the lower priority traffic. This is how higher quality of service is guaranteed for higher prioritized traffic.

EDCA needs four parameters to distinguish traffic types. These are CWmin[AC] and CWmax[AC] (minimum and maximum contention window lengths for each access category), AIFS[AC] (arbitration inter frame space) and TXOPLimit[AC] (maximum duration an access category can use to send a frame). The values of these parameters are advertised periodically by the access point within a management frame called ”EDCA parameter set element”. Access points can tune the values of these parameters at run time with respect to channel load and networking policies. How to tune the parameters efficiently is as yet an open issue and will be product specific on each access point.

The contention procedure is very well defined for EDCA, making simple reasoning possible, e.gif there is more traffic on the channel, there will be more collisions during contention. Also there will be more stations occupying the channel resulting in higher delays. Although some exceptions exist, which will be discussed in the third section, the loss, delay and jitter rates of traffic streams are mostly directly proportional to the load element parameters. This property was used to develop an admission control scheme by [6].

2.2 Hybrid Coordination Function Controlled Channel Access (HCCA)

The hybrid coordinator uses HCCA in order to make sure that strict QoS requirements such as bounds on delay and loss rate of real time traffic streams are satisfied. During transmission, the hybrid coordinator has a higher medium access priority compared to non-access point stations. Thus, the hybrid coordinator can send its own packets and assign HCCA TXOPs to other stations before any station using EDCA can access to the idle channel. This allows the hybrid coordinator to control transmissions.

If a traffic stream has constraints which should be dealt with explicitly, the owner station of this stream can tell the access point that this specific traffic stream needs to be polled in the schedule of HCCA. In order to be polled in the schedule of HCCA, the owner station sends a management frame to the QAP, which includes the traffic specification (TSPEC) of the current stream. The traffic specification includes necessary information to describe a type of traffic like nominal MAC service data unit (MSDU) size, mean data rate, suspension interval, delay, surplus bandwidth allowance and maximum service interval.

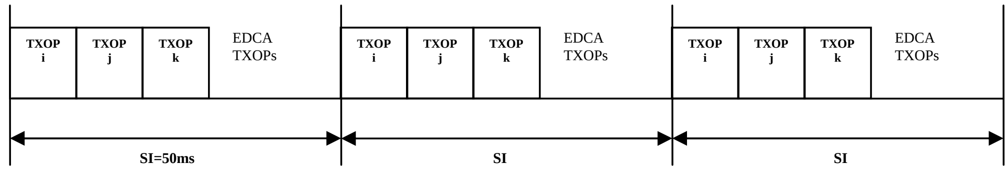


Figure 2. Schedule for three QSTA streams named i,j and k

The service interval (SI) is the time between successive transmission opportunities assigned to a traffic stream. Using this information, the hybrid coordinator should decide whether or not to accept the incoming traffic stream and what kind of scheduling mechanism to use in case of acceptance. This decision algorithm is an open issue in the standard and is one of the most challenging tasks to be realized.

The standard recommends a scheduling method for HCCA using service intervals. This is illustrated in Figure 2. As opposed to Figure 1, where a regular pattern for the access phases does not exist, the recommended scheduler of the standard has an ordered structure. One can see that the TXOPs given to different traffic streams are repeated at the beginning of each service interval so that stations can send their packets periodically. To determine the length of service interval the recommended practice of the standard selects a number which is smaller than the smallest maximum service interval and which is a submultiple of the beacon interval. This means that the length of the service interval is dependent on the incoming traffic. However, information on the length of the service interval is only implicitly available to the stations. Additionally the amount of time reserved for contention free period is left to the hybrid coordinator. Hence the HCCA TXOPs must be smaller than the so called dot11CAPlimit (maximum percentage of time that can be reserved for the controlled access phase). These two variables (the length of the service interval and the time reserved for the contention free period) are the main factors determining the schedule. In Section four we will concentrate on the information quality of these two variables as they are part of the QBSS load elements. Using simulation results we will show that depending on these variables the new protocol exhibits unpredictable behavior. This unpredictability implies that the load element parameters cannot give reliable information about the anticipated QoS from an access point.

3 Simulation Environment

We consider as infrastructure a QoS enabled basic service set (QBSS) composed of a QoS enabled access point (QAP) and a number of stations (QSTAs) associated with the QAP. A slightly modified version of Qiang Ni's ns2 implementation of EDCF/hybrid coordination function [12] is used to perform simulation runs based on this infrastructure [1]. According to the results of [11], we define 7 different traffic types by combining the defined traffic types of [1, 4, 15]. Each station starts only one stream using one of the traffic types during each run.

1. Bidirectional constant bit rate (CBR) voice traffic using UDP with a packet size of 160 bytes and packet interval 20ms (8 Kbytes/s) corresponding to the VoIP codec G.711. (1st access category)

2. CBR video traffic using UDP with a packet size 1280 bytes and packet interval of 10ms (128 Kbytes/s). (2^{nd} access category) (High quality Video)

3. 12 simulated VBR video traffic streams using UDP with minimum packet size of 28 and maximum packet size of 1024 bytes with an average packet interval of 23ms corresponding to 30Kbytes/s. (2^{nd} access category) (Average Quality Video)

4. Bidirectional interactive traffic using TCP with a packet size of 1100 bytes and exponentially distributed arrival rates having an average of 50ms on time, 30ms off time and sending rate of 60Kbits/s during on times corresponding to an average of 10Kbytes/s. This complies with the interactive traffic definition of 3GPP TS 22.105 and ITU G.1010. (3^{rd} access category)

5. CBR Background traffic using UDP with a packet size of 1200 bytes and inter arrival time of 100ms corresponding to 12Kbytes/s. (4^{th} access category)

6. VBR Background traffic using TCP with a packet size of 1200 bytes and exponentially distributed inter arrival times having an average of 1000ms off and 1000ms on times with a sending rate of 300Kbits/s corresponding to heavy load 160Kbytes/s traffic. (4^{th} access category)

7. VBR Background traffic using TCP with a packet size of 1200 bytes and exponentially distributed inter arrival times having an average of 1000ms off and 200ms on times with a sending rate of 100Kbits/s corresponding to low load 11Kbytes/s traffic. (4^{th} access category) (3GPP TS 22.105 Web Browsing- HTML definition.)

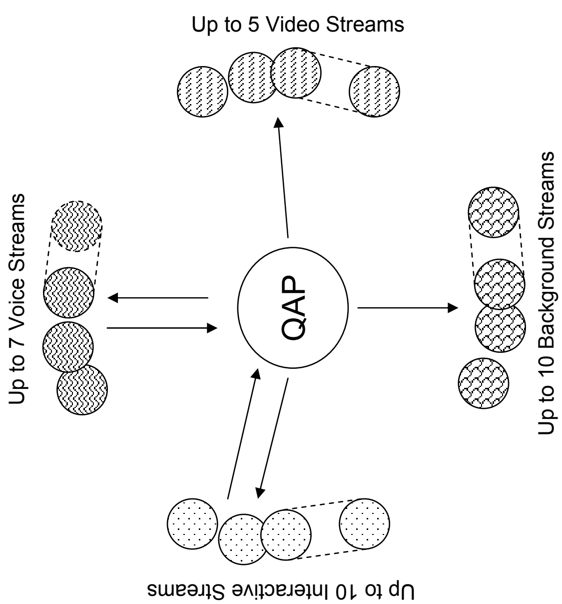


Figure 3. Illustration of the Simulation Scenario

Although 802.11e defines many parameters, we focused on the service interval (SI) and the amount of time reserved for HCCA as system specific variables because they are the main factors determining the scheduling in a beacon period. Together with the considered traffic types, we input a total of three variables. We investigate three different scenarios, where HCCA obtains 40%, 80% and 98% of the model time, respectively. We chose service intervals of length 4.5ms and 50ms as they seemed representative. A simulation takes 30 seconds model time. Traffic streams enter within the first 5 seconds and 20 seconds were chosen as initial transient phase where the measurements of delay, jitter and loss rates are discarded. The simulation results typically converge to steady state within the first 10 to 15 seconds. The traffic load in a simulation is composed of up to 7 bidirectional voice traffic streams (1st traffic type), 5 video traffic streams (2^{nd} or/and 3^{rd} traffic types), 10 bidirectional interactive traffic streams (4^{th} traffic type) and 10 background traffic streams (5^{th}, 6^{th} and 7^{th} traffic types). The issue of mobility is ignored in the simulation. Considering mobile stations is left for future work.

Table 1. List of Simulation Parameters

Bandwidth	11Mbps
PLCPTransmissionrate	1 Mbps
RTSThreshold	3000μs
ShortRetryLimit	7
LongRetryLimit	4
slotTime	9μs
AIFS(1,2,3,4)	$1, 2, 6, 12$
CWmin(1,2,3,4)	$7, 15, 15, 31$
CWMax(1,2,3,4)	$15, 31, 255, 1031$

4 Results

We simulated an access point under the traffic load as described in the previous section. The considered metrics are delay, jitter and loss rates of a traffic stream to demonstrate QoS received by the user. For VoIP streams (1st traffic type), as opposed to the other traffic types, we evaluate the results in terms of the mean opinion score (MOS) values. The MOS is a widely accepted metric of industrial organizations to measure the quality of VoIP applications which is defined in ITU-T Rec. G.107 [9, 8]. MOS rates phone calls on a scale of 1 to 5. The quality of a call is sufficient as long as the MOS value is higher than 3.6. The MOS value is a function of the rating factor R, which again is defined in ITU-T Rec. G.107 as

$$R = \text{Ro} - \text{Is} - \text{Id} - \text{Ie-eff} + \text{A}. \quad (1)$$

$$MOS = 1 + 0.035R + R(R-60)(100-R)7 * 10^{-6} \quad (2)$$

The factor Is represents impairments occurring simultaneously with the voice signal, Id represents delay impairments and Ie-eff represents codec impairments. Additionally 'A' is the compensation of impairments when there are is some advantageous condition on the user side. Ro, Is and Id are other impairment factors influencing the total MOS value [9]. To calculate the MOS values we used a web-based interactive tool in which a number of default values are preset [10].

The aim of the following sections is to find parameters that are indicative for QoS of each traffic type (like voice, or video traffic) in an environment exposed to mixed traffic as described above. The QBSS load element is the only element that informs the stations about the load of an access point. For this reason we measure the amount of useful information in the QBSS load element through its correlation with our QoS metric of interest. We expect that channel utilization and the number of connected stations show negative correlation with all QoS metrics while the available admission capacity correlates positively with all QoS metrics. Note that alternating sign of the correlation across the system parameters as well as a high variability indicates low reliable expressive power of the QBSS load element. In case not otherwise stated, the 99% confidence intervals of the results lie at most within $\pm$ 12% of the given correlation results.

4.1 Voice Traffic Results

To find out what system parameters are indicative for the obtained MOS values of voice streams we simulated different scenarios with two variables, the service interval length and the percentage of time reserved for HCCA. We distinguish two cases of service interval length, 4.5ms and 50ms and three different percentages of time reserved for HCCA, 40%, 80% and 98%, as shown in the total of six different configurations in Table 2. This table summarizes the correlation between MOS values and the components of the QBSS Load element and between MOS values and the number of voice streams.

We observe that the number of stations indeed correlates negatively with the QoS metric, but correlation is for none of the system configurations more than roughly $|30|$ which we consider low correlation. There is an intuitive explanation for this result. Some stations, like the ones producing small background traffic, put very little load on the system and hence have very little effect on QoS. Therefore one cannot estimate QoS based on the number of stations. It should be noted, however, that for the larger service interval the MOS value and the station count correlate slightly more since the hybrid controller can reserve transmission opportunities for each demanding stream and the remaining time used for EDCA determines the quality of the packets sent later on which is directly correlated with the number of stations.

For the short service interval, the number of connected stations correlates less with the MOS value and if 98% of the time is reserved for HCCA, lower priority streams obtain HCCA TXOPs only if there is no first priority stream requiring admission. Similar to the above argument, then the number of stations does not correlate strongly with the MOS value of the first priority stream.

We observe only a negligible correlation between the channel utilization and the MOS value in case of long service intervals. This is because the voice traffic has the highest priority and in many cases does not get disturbed by lower priority traffic as it receives sufficient HCCA TXOP. Even if the TXOP given by HCCA is not enough, voice streams still benefit from their short contention windows during EDCA. When using short service intervals, however, correlation between channel utilization and MOS value becomes rather high and positive. As seen in Figure 4(a), a linear regression with least square optimization gives:

$$MOS = 2.66 * utilization + 1,67 \tag{3}$$

with an R^2 value of 0.22. The R^2 value shows the goodness of fit and is calculated as:

$$R^2 = 1 - \frac{SSE}{SST} \tag{4}$$

where SSE is the sum squared error and SST is the total variance in the data. As R^2 approaches 1 the regression approaches a perfect fit. Although the R^2 value is low in this case, the important thing here is that we have a statistically significant and positive slope of MOS with respect to channel utilization. The 99% confidence interval of the slope of the linear regression is [2.38,2.93]. Additionally the 99% confidence interval of the correlation '0.55' which is given in Table 2 is [0.49,0.61]. Both analysis approve that MOS value increases with the channel utilization. This is counterintuitive since we expect high service quality during low utilization. We can explain this behavior as follows. The TXOP given by HCCA is limited within short service intervals. For this reason the router cannot receive enough HCCA TXOP to send its downlink packets. Consequently it has to use the time in EDCA which is also limited for all the downlink packets that have be to transmitted by the router. This increases the internal collisions on the MAC layer of the router and doubles the lengths of the contention windows after each collision. Therefore delay on the MAC layer of the router increases substantially. Correspondingly, the total number of

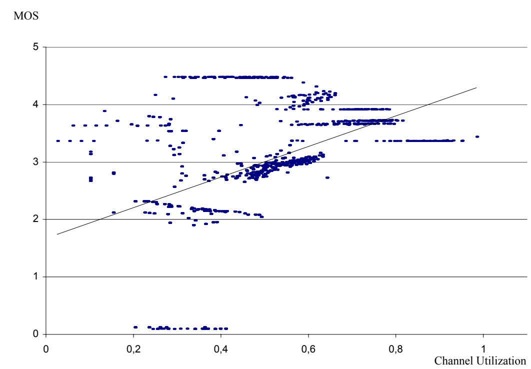
Table 2. Correlation of voice streams' MOS values with the QBSS load element parameters and the number of voice streams under different SI and HCCA percentage

	40%HCCA		80%HCCA		98%HCCA	
Service Interval	4.5ms	50ms	4.5ms	50ms	4.5ms	50ms
Station Count	-0.11	-0.29	-0.27	-0.25	0	-0.19
Channel Util.	0.55	0.01	0.20	-0.01	0.28	0.05
Avail. Adm.C.	0.06	0.26	0.14	0.59	0.11	0.08
1st priority #	-0.86	-0.69	-0.90	-0.70	-0.79	-0.73

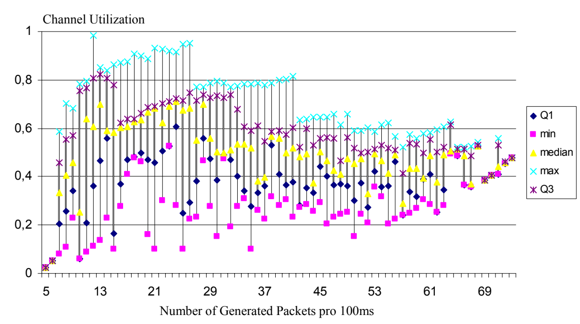
packets on the interface queue (See [12] for more detail on the interface queue we are using) of the router reaches the maximum level very fast and new generated packets are dropped directly before entering into the MAC layer. As a result the load on the MAC layer and so the channel utilization becomes less because of the decreasing number of downlink packets. This is mostly true for video traffic which is generated every 10ms with high packet load. A high number of video packets are dropped and instead relatively more background packets with less packet load and longer contention windows are sent from the MAC layer. As seen from Figure 4(b), the maximum and the median of the utilization decrease with the total number of generated packets. Therefore, it is not the channel utilization which causes a positive correlation with the MOS value for voice traffic, instead the longer delays and higher loss rates of high load traffic on the interface queue which causes lower channel utilization.

In case of longer service intervals, more available admission capacity means better MOS value for voice traffic. If the percentage of HCCA is high enough, available admission capacity means that TXOPs could have been assigned for all the traffic on the access point, which leads to a positive correlation with MOS values. Such a relationship does not exist if there is a small service interval. Available admission capacity reaches a minimum just after the start of one video stream and one voice stream. Hence, there is never enough time for HCCA to distribute sufficient TXOPs. Therefore, depending on the percentage of HCCA being used, the results are mainly affected by the length of EDCA and not HCCA.

As illustrated in the last row in Table 2, we find that the number of connected 1^{st} priority streams correlates much more (and negatively) with the MOS value than any of the QBSS load element parameters. Hence it seems to be a good indicator for the expected QoS of voice streams.



(a) Channel utilization versus MOS. Each point represents the value of MOS or Channel utilization measured by a voice stream in one simulation run within different traffic combinations.



(b) Number of generated packets pro 100ms versus Channel utilization

Figure 4. The relationship between Channel Utilization and MOS value during small service intervals

4.2 Video Traffic

Because there is no metric like MOS defined for video traffic, we present the correlation of the information element with delay, jitter and loss rates. In fact, as given in Table 3, the results are very unstable for video traffic. If the traffic combination changes the results change also. Nevertheless the sign of the correlation is constant. The delay and the number of stations correlate positively, as expected.

Since voice traffic has higher priority than video traffic, the number of voice traffic streams increases the delay of video traffic directly. Additionally, video traffic streams affect each other more than all the other traffic streams, because video packets come more often and are larger. This causes a positive correlation between station count and delay and loss rates. If the number of traffic streams associated with the access point increases, the schedule of the HCCA becomes more stable and therefore jitter decreases, which results in negative correlation. Channel utilization and available admission capacity show nearly no correlation with delay, jitter or loss rate.

In most cases the number of video streams has a high correlation with delay, jitter and loss rates of the video traffic. This is due to the fact that video streams are relatively heavy loaded and constitute the main channel utilization. If the service interval is small, at most one video stream can receive a HCCA TXOP and the remaining ones use the contention period. Because the contention period is short and video packets come very often, the bandwidth reserved for the video traffic is not enough and the loss rate increases suddenly. Therefore it is not possible to have more than two video streams with an acceptable level of QoS.

4.3 Background Traffic

The correlation between load element parameters and the delay, jitter and loss rate of background traffic streams is also heavily dependent on the service interval length. In the longer intervals, the correlation is easy to explain. It is mainly due to the fact that background streams have to wait for all the other traffic streams and only get EDCA TXOPs. As the number of stations increases, delay, jitter and loss rate increase as well (See Section 2.1). The same holds for the utilization. If the utilization is high, then either the traffic streams have high payload, or there are many streams. Because background traffic has the lowest priority, it has to wait for the others, resulting in higher delay, jitter and loss rate. At the same time the number of background streams correlate strongly with delay, jitter and loss rate. This is mostly due to the fact that the remaining time in the contention period is shared between the background streams. (There is no background traffic in the contention free period.)

When the service interval is short, the correlation is the inverse. There is only little time for the contention period in this case. The streams have little chance to have a channel access during one service interval. Nearly all streams share the contention period because there is no enough TXOP given by the HCCA. If also free time in the scheduler increases, then even less TXOP is assigned to video or voice streams because the expected transmission time of their packets are longer than the available admission time. If the number of streams increases then packets are frequently dropped on the interface queue of the access point, especially packets of video streams. This results a smaller number of high priority high load packets on the MAC layer. Additionally the contention window doubles each time especially for the packets of video streams causing longer delays. These factors decrease the advantage of high priority high load traffic with respect to the background streams substantially. Consequently, background traffic has more chance to win a TXOP during a contention period.

In Figure 5, we see four different subsets of points: an upper bound, two bulks in the middle and a line of many observations with extremely low delay. The upper most subset belongs to the simulation runs whith up to 2 voice and up to 1 video traffic streams. The second subset belongs to the runs with up to 4 voice and 2 video streams. The following subset has up to 5 voice and up to 3 video streams. The last one has up to 7 voice and up to 5 video streams. Because of the total number of runs, the effect of the first three subsets on the correlation is relatively low, although they correlate positively with channel utilization. In fact, this also shows that QoS of the background streams is determined by the situation of the other streams that have higher priority than the background traffic.

As opposed to the results of voice and video streams, the number of background streams does not have any correlation with delay, jitter and loss of background streams, if the service interval is small. But the correlation becomes significantly higher as the service interval gets longer. This is most probably due to the fact that in longer service intervals higher priority streams receive sufficient TXOP. Hence, background streams have to compete with each other for channel access.

Table 3. Correlation of video streams' loss, delay and jitter rates with the QBSS load element parameters and the number of video streams under different SI and HCCA percentage

	4.5ms SI			50ms SI		
	Delay	Jitter	Loss	Delay	Jitter	Loss
	40% HCCA					
Station Count	-0.11	0.08	0.22	0.23	-0.23	0.22
Channel Util.	-0.21	0.05	-0.40	-0.05	-0.14	-0.06
Avail. Adm.C.	-0.23	0.59	0.68	-0.02	0.07	-0.02
1^{st} priority #	0.69	-0.37	0.11	0.90	-0.71	0.89
	80% HCCA					
Station Count	-0.11	0.08	0.22	0.23	-0.23	0.22
Channel Util.	-0.21	0.05	-0.40	-0.05	-0.14	-0.06
Avail. Adm.C.	-0.23	0.59	0.68	-0.02	0.07	-0.02
1^{st} priority #	0.69	-0.37	0.11	0.90	-0.71	0.89
	98% HCCA					
Station Count	0.12	0.01	0.15	0.26	-0.15	0.29
Channel Util.	-0.18	0.10	-0.18	-0.09	-0.07	0.23
Avail. Adm.C.	0	-0.02	0	0.13	0.04	-0.19
1^{st} priority #	0.57	0.07	0.51	0.72	-0.81	0.83

Table 4. Correlations of background traffic; SI and HCCA percentage versus QBSS load elements and background traffic number

	4.5ms SI			50ms SI		
	Delay	Jitter	Loss	Delay	Jitter	Loss
	40% HCCA					
Station Count	-0.09	-0.09	-0.08	0.39	0.32	0.27
Channel Util.	0.17	0.18	0.15	0.29	0.31	0.33
Avai. Adm.C.	-0.06	-0.06	-0.05	-0.14	-0.11	-0.08
4^{th} priority #	0.03	0.03	0.02	0.43	0.38	0.38
	80% HCCA					
Station Count	-0.42	-0.35	-0.29	0.43	0.41	0.39
Channel Util.	-0.08	-0.19	0.02	0.29	0.29	0.27
Avai. Adm.C.	0.49	0.39	0.36	0	0	-0.40
4^{th} priority #	0.04	0	0.08	0.85	0.81	0.79
	98% HCCA					
Station Count	-0.47	-0.49	-0.49	0.36	0.43	0.42
Channel Util.	-0.37	-0.43	-0.43	0.38	0.32	0.35
Avai. Adm.C.	0.42	0.43	0.43	0.03	0	-0.38
4^{th} priority #	0.01	-0.01	-0.05	0.88	0.69	0.71

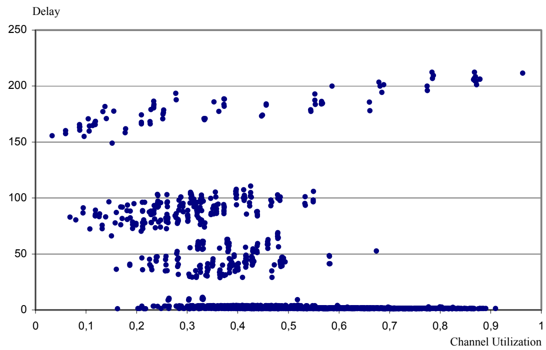


Figure 5. Delay as a function of channel utilization for background traffic

5 Evaluation of Results and Enhancement Recommendation

The results of the Sections 4.1, 4.2 and 4.3 show that the load element parameters channel utilization and available admission capacity are capable of giving meaningful information in some of the parameter combinations because they are moderately correlated with the metrics of interest (MOS or delay, jitter and loss rates) in these cases. However, this information is not reliable because it depends on many other variables and is not stable. The station count is in none of the cases a reliable source of information as there is no observed correlation higher than $|0.30|$. Such a low correlation is not helpful in decision making. Even more so since there is another parameter, the number of streams belonging to the respective priority class, that correlates much stronger with the respective QoS metric.

The number of any kind of traffic streams that can be transmitted over an access point has a maximum value and this depends on the standard being used. For 802.11b the maximum number of voice calls using G.711 codec is about 5 which can be further optimized to 7 with more efficient algorithms [5]. Therefore we compared the correlation between the number of traffic streams in each priority class and the QoS indicator values (MOS, delay, jitter and loss rates). The results were for some cases as high as $|0.9|$. This number is significantly higher when compared with the correlation results of the QBSS load element. Therefore QoS estimates should use the number of the respective applications being transmitted over an access point. Instead of costly monitoring delay, jitter and loss rates, one could use simple parameters like the number of streams of a priority class. This of course depends on the efficiency of the algorithm of the access point firmware. However the same is true for any other parameter that can be used for estimating QoS before the transmission is started. Hence, we recommend adding a vector holding the number of stations using each priority in the QBSS load element. This vector introduces negligeable load on the beacon frame. An extension of the current draft with the vector of station count using different priority levels can ease the access point selection procedure substantially.

6 Conclusion

In this paper, we presented the QBSS load element and its use in the context of 802.11e. Our simulation results showed that the fields of the QBSS load element do not always allow to make a valid judgement about perceived service quality.

In order to delineate the poorness of the QBSS load element information, we listed the results of the correlation between the QBSS load element parameters and QoS factors like delay, jitter and loss rate. We showed that, in most of the cases the correlation is very low and unfortunately even the sign of the correlation can change if one uses a different set of parameters.

We observed that in all cases with decreasing HCCA percentage, the decision accuracy improved significantly supporting our claim that the HCCA brings extra irregularity and complexity to the new standard. We conclude that, depending on the internal configuration of the QAP, meaning the settings of the 802.11e relevant parameters, the provided network service cannot be bound barely on the load information.

Although we presented two of the most important parameters affecting the performance of 802.11e, incorporating more parameters into the decision process, for instance considering the number of traffic streams in different priorities, can improve the accuracy of the decision. We are going to analyze other parameters of the TSPEC like surplus bandwidth allowance and delay bound, which will be included in our next study.

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